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ABSTRACT

This study assessed whether redundant stimuli are beneficial in motor performance, and how redundant information is processed, using 11 male and 11 female undergraduate students. A minimum information tracking task was presented to subjects on a computer in seven conditions. Overall, evidence seems to point to enhanced performance when information is presented redundantly. Logic predicts that the same information presented through more than one modality should facilitate performance on a minimum information tracking task presented by computer. Auditory, visual, and tactile signals were delivered in trimodal, bimodal, or unitary conditions. It was predicted that the trimodal condition would produce the best performance, with the bimodal performance superior to that of one mode alone. These predictions were not supported. Statistically, there was no difference between the visual alone condition, the bimodal conditions with a visual element, and the trimodal condition. The poorest performance came from the tactile alone condition. Explanations for these results are considered, and it is suggested that the task may need to be more difficult to explore differences in responses adequately. (Contains 19 references.) (SLD)

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The Effects of Redundant Visual, Auditory, and Tactile Stimuli on a Minimum Information Tracking Task

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by
Steven C. Miller

Many everyday tasks involve the use of redundant stimuli. For example, when one is driving a car and runs off the road one feels the vibration from the wheels going over a rough surface, hears the sound of the tires hitting bumps, and sees the road in a position where it is not supposed to be. This event portrays a common example of redundant stimuli. That is, the feel and sound of a new surface and the sight of the road not being in the correct position are essentially providing the same information, that of not being on the road. From this example two main questions may be asked. Are redundant stimuli or signals beneficial in motor performance and how is redundant information initially processed? This study hopes to shed some light on these questions.

Common sense suggests that two sources of information would be better than one; however, in reality this is not always true. There has been a general observation that redundant bisensory stimuli improves or facilitates signal detection performance (Hopkins 1967; Grice, Canham, and Boroughs 1984) and response time (Colonius 1988). Other studies, especially involving tracking tasks, have produced results not completely supportive of this general observation. McGee and Christ (1971) hypothesized that tracking performance would be better when stimuli were presented in two modalities as opposed to one. In their study, a pursuit tracking display was used for the visual tracking alone condition. In addition, it was used in combination with one of two auditory conditions, either a white noise of 50 db. presented simultaneously with visual changes for 40 msec. or four separate tones which corresponded to four visual positions and equivalent duration and intensity to the white noise. Indeed, performance was facilitated with bimodal stimuli regarding measures of the proportion of long lags and integrated absolute error. Long lags were defined as reaction time delays of more than 150 msec. from the time of a target displacement and there were fewer occurrences of long lags with bimodal stimuli presentations. Integrated absolute error was analogous to the average distance away from the target measured through voltage differences which corresponded to the target and cursor positions. Although these measurements supported McGee's and Christ's hypothesis, spatial accuracy, measured to the nearest mm in terms of overshoots and undershoots and then averaged as a function of the trial number, showed no beneficial bimodal effects. The visual alone and visual plus tone conditions were determined equal and both were superior

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to the visual plus white noise condition. The results were considered in conclusive in that the addition of redundant auditory information can either inhibit or facilitate performance depending on situational aspects.

McCord (1989) also predicted a facilitation effect on the presentation of redundant auditory and visual stimuli in a compensatory tracking paradigm. Specifically, he predicted that a criterion level of performance would be achieved more quickly through stimuli presented bimodally than unimodally. McCord's visual stimulus was a cursor which varied in horizontal position and the auditory stimulus was 64 gradations in pitch spanning an approximately two octave range. Since no mention was made regarding auditory stimulus intensity, the assumption is made that the auditory intensity level remained constant. His bimodal condition was a combination of the auditory and visual stimuli. From the two dependent measurements, root mean square of cursor or tone movement and number of trials to meet the criterion level of performance, a synthetic variable was manufactured. This synthetic variable was labeled "general task difficulty" (p. 280). The best performance was observed when the visual modality functioned alone. This was interpreted in the light of task difficulty; in other words, the visual task alone was considered less difficult to control than either of the other two conditions. McCord concluded that the auditory stimulus was a distraction, actually hindering performance.

In summary, the evidence for redundant stimuli facilitation is inconclusive. Maybe Eriksen (1988) put it best when he stated, "we still do not know whether it would help if opportunity did knock twice" (p. 191).

This study looks at performance as it is affected by redundant stimuli presented in multimodal channels. Approaches examined by a review of the literature are the signal detection theory (Swets, Tanner, and Birdsall 1961) and separate activation and coactivation models (Miller 1982). These approaches have examined a variety of issues through different focal points. Specifically, this study used a minimum information tracking task to determine how performance is affected by unimodal, bimodal, and trimodal redundant stimuli.

A minimum information tracking task is one that only provides information about the error direction without information of the magnitude of the effort. For example, an auditory signal in the right ear would indicate that the error is to the right; therefore, error correction would require a deflection of the control device to the left. The intensity and the pitch would remain constant. Likewise, a constant vibrotactile stimulus to the right forearm or a light in the right visual field would indicate the same information.

The rationale for using a minimum information tracking task instead of response time or a compensatory tracking task is twofold. First, a tracking task requires more of a continuous action than response time. While tracking, subjects must continually monitor their sensory inputs and react when signals change or appear and disappear. Also, their reactions or joy stick manipulations, in this case, do not necessarily correct the error instantly as would be the case with a typical response time task. The intent is to make it necessary for information to be processed more continually, thus, increase the opportunity for error. This should magnify the effects the stimuli has on

manual control and provide a clearer picture of how motor responses are affected by sensory information.

Secondly, a compensatory tracking task provides a representation of both the error direction and the error magnitude through one moving component (Roscoe, Corl, and Jensen 1981). Equivalent directional errors to the right and left are discrete and relatively easy to present through different sensory modalities. However, producing equivalent redundant signals for a continually changing error magnitude is much more difficult, especially when the speed of control manipulation is important, which is usually the case in tracking tasks. Error magnitude requires that a more continuous scale of information be presented. A specific distance presented visually will not naturally equate to an auditory tone altered by pitch or intensity. The same applies to tactile stimuli. Although not mentioned by McCord (1989), this problem may provide one possible explanation for the superiority of the unimodal visual stimuli over the bimodal auditory and visual stimuli in his 1989 study.

LITERATURE REVIEW

The evidence for performance improvements when redundant stimuli are presented is broad and widely varied. Simon and Overmyer (1984) demonstrated that redundant color (visual) and shape (visual) coding lead to quicker response times than single dimension color coding but not significantly faster than shape coding. Powers and Madison (1987) showed that kindergarten children who had speech production problems performed better in scores of discrimination skills after being instructed to attend to bimodal stimuli than those just presented with either auditory or bimodal stimuli. Also, bimodal stimuli produced better performance than auditory stimuli alone for the subjects not receiving the instructions. Melara, DeWitt-Rickards, and O'Brien (1989) produced evidence that correct eyewitness identifications could be improved if actual suspect lineups had both visual and auditory information, as opposed to the standard of just visual information. Finally, Doll and Hanna (1989) demonstrated a bimodal advantage in the signal-to-noise ratios necessary for signal detection in sonar displays. However, the following discussion focuses on two specific areas. They are the signal detection theory (Swets, Tanner, and Birdsall 1961) and separate activation and coactivation models (Miller 1982).

Signal Detection Theory

Signal detection theory provides one approach to the general perceptual capabilities of humans (Swets, Tanner, and Birdsall 1961). Hopkins (1966) applied the signal detection theory to the interaction of redundant information through more than one modality. After threshold detection levels were established for auditory and visual signals for two subjects, signals were presented separately and then simultaneously with specific probabilities of occurrence. Simultaneous signal presentation produced a "marked increase" in the probability of detection over the presentation of signals separately (p. 4). The explanation for this was the simple adding of probabilities. In other words, the auditory and visual modalities performed independently. The detection increase was attributed to the fact that the individual signals, auditory and visual, each had their own chance of one of them being detected was increased.

Loveless, Brebner, and Hamilton (1970) indicated that intersensory interactions may not be as simple. Although their main focus was also signal detection theory, their context was broadened to include difficult detections, recognitions, and discriminations. They addressed the possibility of specific modality interactions, not just the simple summation of probabilities. Even though increased bisensory efficiency was confirmed they were unable to establish any uniform strategies to link the rules regarding the integration of bisensory stimuli.

Separate Activation versus Coactivation

When performance is improved by the presentation of redundant signals it is called the redundant-signals effect (Kinchla 1974). There are two theoretical models that account for the redundant-signals effect (RSE). Raab (1962) used the term statistical facilitation, while Miller (1982) used the term separate activation to describe the first model. Here, redundant stimuli are considered separate and the one that is detected first is the one that is acted upon. Activation of a response must come from one signal acting separately and reaching a criterion level. In other words, reactions to equivalent simultaneous signals presented through different modalities will be responded to individually according to the signal that is sensed or perceived first. This is analogous to one signal or modality being faster than the other on a specific trial. On subsequent trials the other modality may produce a faster signal. Hence, the term "race" model has also been used to describe this hypothesis (Miller 1982; Grice et al and Colonius 1984).

The second model is called coactivation (Miller 1982). In this model the information in the stimuli are combined producing gains that result in response times even lower than those that could be produced by the separate activation model (Eriksen 1988). In Miller's description of coactivation the response to redundant signals would be influenced by both components working in a combined effort to satisfy the criteria necessary for a response.

Consider the scull, a light racing boat operated by one, two, or four oarsmen. Separate activation is analogous to having two separate sculls, each with one oarsman (individual modality signals) racing to a finish line (the criterion necessary for a response). The scull or signal that reaches the finish line first is the one that initiates a response. The one that finishes second has no effect for this particular race, but may finish first the next race. As a comparison, coactivation is analogous to two oarsmen in the same scull rowing in cooperation together to reach the finish line. The two oarsmen scull may produce times faster than is possible by a single oarsman scull.

In conclusion, the overall evidence seems to point to an enhanced performance when information is presented redundantly. Therefore, logic predicts that the same information presented through more than one modality should facilitate performance on the minimum information tracking task used in this study. In other words, the prediction here is that the trimodal condition will produce the best performance. Any bimodal condition will produce performances better than either of the individual elements from which it was composed. For example, the visual-auditory condition will produce a better

performance than either the visual alone or the auditory alone condition.

METHOD

Subjects

The subjects for this study were 25 undergraduate 201 Psychology students, 14 males and 11 females. Three male subjects were eliminated from the study. Two were eliminated due to stated difficulties with the stimulus presentation and one was eliminated by random selection to produce a balanced experimental design of 11 males and 11 females.

Requirements for participation were that subjects have normal or corrected vision and no known hearing loss. Of the 22 subjects, 21 had normal or corrected vision in both eyes and all had no known hearing loss. One female subject had normal vision in one eye and 60:60 vision in the other eye. Because she reported no difficulty seeing the visual stimuli and her scores indicated no difficulty, her data were used.

All the subjects were from 18 to 21 years old. There were 20 right handed subjects and two left handed subjects. Each subject used their dominant hand to control the joy stick. Subjects received extra class credit for their participation and a chance to win a $25.00 cash prize.

Apparatus and Materials

A minimum information tracking task was presented by a Zenith 258 computer. The cursor disturbance function was computer generated mathematically by the summation of five sine waves having different frequencies. The visual signal was presented on a Zenith color computer monitor and consisted of a yellow box, one mm wide by two mm tall, placed on either the right or left side of a computer screen. The horizontal position of the visual signal was seven mm from the center of the screen to the box. The auditory signal was produced by a Radio Shack miniature piezo buzzer, number 273-074. It was powered by two C batteries and created a constant tome of 4.2 ± 0.5 kHz. A buzzer was mounted inside the right and left side of a set of head phones. To obtain a comfortable sound level, determined subjectively, it was necessary to muffle the buzzers.

The tactile signal was a vibrotactile stimulus presented on the back of either the right or left forearm. Placement of the display was midway between the elbow and the wrist. The vibrotactile displays were constructed from Radio Shack 1.5-3.0 volt DC motors, number 273-223. The shaft was unbalanced to create the vibration. The unbalanced motor was encased in PVC plumbing fittings and was mounted on an archery arm guard. The arm guard had adjustable elastic straps with velcro ends for securing it to the subject's forearm. A vibrotactile display was constructed for each forearm and powered by a three volt DC converter. Controlled by the computer, an external switching device was developed and used for the auditory and tactile signals.

All the signals were presented at an intensity above absolute threshold. When presented the signals remained active until the error was corrected to within tolerance standards, a space four mm wide centered in the middle of the computer screen. In other words, when the invisible cursor was more than two mm from the center of the screen a signal or signals, depending on the condition, was given to the side of the error. No stimulus meant the subject was on target

and at no time were simultaneous signals given to both the right and left side.

The control devices were Measurement Systems 546 joy sticks mounted on the right and left arms of the subject's chair. All subjects used their dominant hand for tracking. A Scientific Solutions A/D board interfaced the joy sticks to the computer. Although the joy sticks allowed physical movement other than right and left, only the amount of right or left horizontal displacement effected the cursor. Determined by the displacement magnitude, the effect was progressively stronger the further the joy stick was moved from its center position.

Procedure

A verbal explanation of the tracking task was presented to each subject. In the explanation phase, a visual cursor was shown along with either the visual signal or the auditory signal to demonstrate how the cursor reacted under control of the joy stick. Since the subjects were not actually outfitted with the sensory displays during this phase, the tactile signal was not used in the demonstration. This was done to minimize distraction from the visual cursor. The cursor was visible only during this initial demonstration.

Each subject individually performed a minimum information tracking task presented in seven different conditions: (a) visual alone, (b) auditory alone, (c) tactile alone, (d) visual and auditory together, (e) visual and tactile together, (f) auditory and tactile together, and (g) visual, auditory, and tactile together. A dichotomous signal was presented on either the right or left side of the subject. A signal on the right meant that there was error to that side and a correction move to the left was needed. A signal to the left meant the opposite. Each subject performed one set of one minute practice trials on each different condition. A record of the practice set was kept, but was not used in the analysis. The order of conditions in the practice set was maintained in each subject's first respective experimental set. Subjects then performed six additional sets of one minute experimental trials for each condition. A counterbalanced design was employed to minimize the risk of any practice effects.

Measurements were taken by the computer and consisted of root mean square error. Root mean square (RMS) error is a measurement of error magnitude and is analogous to the average deviation from the target.

Note that during the auditory alone and the visual-auditory conditions the computer malfunctioned sporadically beginning with subject number eight. The signal would get stuck, usually on the left side, and the joy stick had no control during this period of time. Every malfunction was aborted and immediately restarted and they became more numerous for the last five subjects. After initial exposure to the malfunction, the subject was given the explanation that the system had a bug in the auditory alone and the visual-auditory conditions. Starting with subject number 22 an explanation of the malfunction being possible was given during the initial instruction process prior to any occurrence of the malfunction.

Of the 22 subjects whose data was used, the auditory alone condition malfunctioned a total of 15 times out of the 154 presentations of that condition, including three times in practice trial sets and twelve times in experimental sets. The visual-auditory condition malfunctioned a total of 18 times out of its

154 presentations, including two times in practice trials and sixteen times in experimental sets. The malfunctions created no obvious effect on performance.

RESULTS

A 7 (Information Conditions) X 6 (Trial) X 2 (Gender) analysis of variance (ANOVA) with repeated measures was performed on RMS error scores. The independent variables were information conditions (within), trial (within), and gender (between). The dependent variable was root mean square error. Due to insufficient error degrees of freedom in the & X 6 X 2 design, a univariate F test for gender effects was performed by collapsing across conditions and using the condition means for each subject. Possible moderating variables, which were controlled were age and handedness. Both age and handedness were controlled by the random assignment of subjects to a prearranged sequence of trials. Age was also controlled by the selection of undergraduate Introduction to Psychology students, while an added control for handedness was having each subject use his or her dominant hand to control the joy stick.

A significant main effect was found for information condition, Wilk's Criterion $F(6,15) = 8.21$, $P = 0.0005$. No main effects were found for gender, $F(1,20) = 1.76$, $p = 0.1999$. No effects were found for either trial, the condition by gender interaction, or the trial by gender interaction. The significant main effect for information condition allowed for four a priori comparisons to be executed. A priori comparison is a comparison formulated to directly test predicted hypotheses before the actual experiment is conducted (Christensen and Stoup 1991). Using Wilk's Criterion, each dual modality condition was compared with the best performing single modality condition that was used to construct its combination of conditions. For example, the visual-auditory condition was compared to the visual alone condition because the visual alone condition had the lower mean RMS error score than the auditory alone condition. Likewise, the trimodal condition was compared with the condition that produced the best performance other than itself. The logic for applying this technique to determine the specific a priori comparisons was appropriate because it insured a conservative test of the null hypothesis if the direction of the mean differences was as predicted (redundant signals effect) and a liberal null hypothesis test if the direction of the mean differences was not as predicted (interference effect).

Specifically, the visual-auditory and visual-tactile conditions were compared with the visual alone condition. The auditory-tactile condition was compared with the auditory alone condition and the visual-auditory-tactile condition was compared to the visual-auditory condition. No significant effects were found for any of the a priori comparisons.

The standard deviations represented a large amount of between subjects error. To examine the position of the means without this error a sign test was used. The trimodal condition and each bimodal condition were compared with each element or combination of elements that were used in its construction. The sign test was significant, $X = 11$, $N = 12$, at $p<.01$. X represents the number of means in the predicted position, while N represents the total number of comparisons tested.

Since the position of the condition means was as predicted, except for the visual alone condition, an additional analysis was performed to explore the possibility of making the distinction between separate activation and coactivation. A 7 (Information Conditions) X 2 (Gender) ANOVA with repeated measures was performed using the fastest (best) performances for each subject in each condition. There was a significant main effect for information condition, Wilk's Criterion $F(6,15) = 6.92$, $P = 0.0011$. Again, no main effect was found for gender using Wilk's Criterion, $F(7,14) = 1.46$, $p = 0.2591$ or for the condition by gender interaction, Wilk's Criterion $F(6,15) = 1.82$, $p = 0.1617$. Four a priori comparisons were executed, using the same pairs of conditions used in the previous analyses. No significant effects were found for these comparisons.

A sign test was also performed on best performance means and was significant, $X = 12$, $N = 12$, at $p<.01$. Again, each combination of conditions was compared to all the possible elemental conditions that could have been used in its construction.

DISCUSSION

It was predicted that the trimodal condition would produce the best performance, while each bimodal condition would produce a better performance than their respective elements of construction. These predictions were not supported by the ANOVA and a priori comparison data for either the overall performances or the fastest performances. however, there was no evidence to support the distraction explanation provided by McCord (1989).

In his study, McCord (1989) credited the lack of bimodal facilitation to distraction. in other words, during the bimodal condition, the auditory task distracted or interfered with the visual information. However, simple interference or distraction doesn't appear to be an accurate explanation for this study's results. Using McCord's explanation, it would be logical to conclude that more non visual information presented with visual information should produce more interference. The trimodal condition should have then produced more interference with visual information than the bimodal conditions with a visual element. in other words. the trimodal condition should have produced more of a decrement in performance than the bimodal visual conditions. This was not the case. Statistically, there was no difference between the visual alone condition, the bimodal conditions containing a visual element, or the trimodal condition.

Even though the ANOVA and a priori analyses did not support the RSE position, the sign tests did provide evidence on its behalf. The sign test for the all-inclusive performances demonstrated that the positions of the conditions were as predicted with one exception. the visual alone condition performed better than the visual-tactile condition. In other words, all the condition means were as predicted except for the visual alone condition. The sign test for the fastest performances was as predicted, without exception. This evidence supports the RSE hypothesis, in other words, conditions with more redundant information generally performed better than conditions with less redundant information.

The evidence supporting the RSE logically supports the separate activation hypothesis also. This deduction is justified any time the positions of the conditions containing more redundant stimuli is superior to the conditions containing less redundant stimuli. In other words, any of the individual sensory modalities could provide the signal that is acted upon during any given race (win the race). Summing the faster individual signals through a set of trials would produce an overall performance better than the individual signals acting alone. However, what is lacking is evidence supporting the coactivation hypothesis. This would have taken performances that couldn't have been explained by the separate activation hypothesis. In other words, the best performances of the conditions containing redundant stimuli would have to be superior by enough magnitude that they could not be explained by the separate activation hypothesis. Another way of explaining it is that at least the top percentage of conditions having redundant stimuli would have top be better than those produced by the best possible individual performances. Evidence to support the coactivation model was not produced by this study.

One question that must be addressed is, why did vision generally appear superior to the other unimodal conditions and the visual-tactile conditions when the overall performances were used? Several explanations are possible. One is that people are more practiced when it comes to visual tracking. People drive cars, play video games, or play tennis, etc. as everyday activities, thus, through the practice of motor control while using visual stimuli, a high skill level has been developed. Another possible explanation, was provided by McCord (1989). he indicated that visual tasks may be more natural for humans due to "more readily available structures for visual-motor control" (p. 281).

Another explanation related to the latter is the principle of S-C-R compatibility (Wickens, Sandry, and Vidulich 1983). S-C-R stands for stimulus-central processing-response. The principle is based on the natural mapping between stimulus and response. Specifically, the principle states that auditory stimuli are more compatible to speech responses, while visual stimuli are more compatible with manual responses. Since the response in this tracking task was manual, the S-C-R principle would predict a visual superiority. This was supported by the data.

This was the first time a minimum information tracking task had been used. Although a decision at this time on its worth as a tool in this type of research would be premature, the fact that no interference effects surfaced reflects positively on the task itself.

The equality of different modality signals is an appropriate concern for redundant stimuli research. This was a primary focus in this study. The poorest performance came from the tactile alone condition, therefore, it is appropriate to assume that the tactile signal alone was not equivalent to the other unimodal signals. This could be due to a servo motor delay in the mechanics of the vibrotactile display during the starting and stopping of the motor. It could also be due to the afferent nerve structure or to central processing. However, a combination of factors is probably the most likely. Since it is not possible to change the afferent or central processing structures of subjects, modifications to make the tactile display equivalent to the

visual and auditory displays would be appropriate for future research. There are two obvious approaches. One is to redesign the vibrotactile display. The display that was used in this study used a very small motor. Although difficult to detect directly, the extra weight used to unbalance the shaft may have been enough to delay the starting and stopping of the motor adversely affecting performance. An oscillating motion, like a buzzer or bell uses, instead of a rotary motion may lessen the effects of inertia that must be overcome in any mechanical device. Another approach is to alter the timing of signal presentation to compensate for the delay.

The lack of significant differences between conditions is attributable partially to large individual differences. However, it may also be attributable, at least in part, to the attempt to make direct measurements while performing a single task. By itself the task may not be sufficiently difficult to demonstrate the real effects of information conditions because the overall performances may be asymptotic. In other words, the performances are at a level that can't be improved upon, rendering a direct measurement insufficient to determine any differences. Future research using the minimum information tracking task may find it necessary to increased the task difficulty, thus increasing the mental workload (Wickens 1979). Ways to approach this are to make the task more difficult or use a secondary task performed simultaneously with tracking. under higher levels of workload, the effects of stimulus modality may be more pronounced.

REFERENCES

Christensen, L. B. and Stoup, C. M. (1991). *Introduction to statistics for the social and behavioral sciences* (2nd ed.). Pacific Grove, CA: Brooks-Cole.

Colonius, H. (1988). Modeling the redundant signals effect by specifying the hazard function. *Perception and Psychophysics, 43*(6), 604-606.

Doll, T. J., and Hanna, T. E. (1989). Enhanced detection with bimodal sonar displays. *Human Factors, 31*(5), 539-550.

Eriksen, C. W. (1988). A source of error in attempts to distinguish coactivation from separate activation in the perception of redundant targets. *Perception and Psychophysics, 44*(2), 191-193.

Grice, G. R., Canham, L., and Boroughs, J. M. (1984). Combination rule for redundant information reaction time tasks with divided attention. *Perception and Psychophysics, 35*(5), 451-463.

Hopkins, H. K. (1966). Interaction of the auditory and visual sensory modalities. *The Journal of the Acoustical Society of America, 41*(1), 1-6.

Kinchla, R. A. (1974). Detecting target elements in multielement arrays: A confusability model. *Perception and Psychophysics, 15*, 149-158.

Loveless, N. E., Brebner, J., and Hamilton, P. (1970). Bisensory presentation of information. *Psychological Bulletin, 73*(3), 161-199.

McCord, D. M. (1989). Do redundant visual and auditory target variables facilitate control behavior? *Perceptual and Motor Skills, 69*, 275-282.

McGee, D. H., and Christ, R. E. (1971). Effects of bimodal stimulus presentation on tracking performance. *Journal of Experimental Psychology, 91*(1), 110-114.

Melara, R. D., DeWitt-Rickards, T. S., and O'Brien, T. P. (1989). Enhancing lineup identification accuracy: Two codes are better than one. *Journal of Applied Psychology, 74*(5), 706-713.

Miller, J. (1982). Divided attention: Evidence of coactivation with redundant signals. *Cognitive Psychology, 14*, 247-27.

Powers, L. A., and Madison, C. L. (1987). Effects of presentation mode on discrimination skills of articulatory disordered children. *Perceptual and Motor Skills, 64*, 775-779.

Raab, D. (1962). Statistical facilitation of simple reaction times. *Transactions of the New York Academy of Science, 24*, 574-590.

Roscoe, S. N., Corl, L., and Jensen, R. S. (1981). Flight display dynamics revisited. *Human Factors, 23*, 341-353.

Simon, J. R., and Overmyer, S. P. (1984). The effect of redundant cues on retrieval time. *Human Factors, 26*(3), 315-321.

Swets, J. A., Tanner, W. P., and Birdsall, T. G. (1961). Decision processes in perception. *Psychological Review, 68*, 301-340.

Wickens, C. D. (1979). Measures of workload, stress and secondary tasks. In N. Moray (Ed.) *Mental Workload: Its Measurement* (pp. 79-99). New York: Plenum Press.

Wickens, C. D., Sandry, D. L., and Vidulich, M. (1983). Compatibility and resource competition between modalities of input, central processing, and output. *Human Factors, 25*(2), 227-248.